Panel Discussion on Need for Isolation of Long Open Boreholes–Selection of Water Sampling Techniques[1]

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Carole Johnson, U.S. Geological Survey
Kathy Davies, U.S. EPA, Region 3

Panel Question 1: How long can you wait between the time drilling stops and when the well is installed to avoid cross contamination as a result of the open borehole? Should long boreholes be avoided to prevent vertical migration of contaminants? When should you consider vertical isolation, and what methods do you recommend?

Ballestero: The answers to these questions are site-specific. Vertical isolation should be considered as soon as is practical. Before drilling a well, you should set a schedule; for example, will drilling be followed by geophysical testing or ground-water sampling? The sequence of events planned will affect the need for vertical isolation. When looking at vertical isolation, I would consider using packers first. Packers are quick, easy, and flexible, but packers may not give a complete seal if no testing has been done to determine the depths of conductive intervals. Well socks, on the other hand, are convenient and provide a complete seal, but they are difficult to get into and out of the well.

Davies: We try to schedule geophysical work followed by vertical profiling with packer tests as soon as the well is drilled. This information is used to decide where to complete the well—usually over just one fracture/fracture zone to avoid cross-contamination issues. A FLUTe or similar device has also been used.

Johnson: The answers to the questions depend on the site, but my primary recommendation is that if the borehole is located in the source area or DNAPL is present, then use a blank liner or a "sock". To use a sock, the depth of the well must already be determined, but the locations of fractures do not have to be known. Socks require a tremendous amount of water management installing and removing socks. If low-permeability fractures are present, you need to use a mini-sock, which is placed outside of the main sock and open to the borehole. As water is injected into the main sock, water is pumped out of the mini-sock from below the main sock, thus facilitating the inversion and installation of the main sock. Otherwise, without the use of a mini sock, it will take a long time to get the sock to sink into a "hydraulically tight" borehole.

To determine the length of time a hole can remain open, the approach must be risk based. For example, we once installed a well in the bedrock in a source area and immediately installed a sock. When we removed the sock to do geophysical logging, the nearby overburden well went dry. When the sock was reinstalled, the overburden well filled up again. Clearly, indicating a strong overburden-bedrock connection, and in a source area leaving some boreholes open can cause long-term affects.

Davies: If we suspect we are drilling in a hot zone, we often drill and sample continuously by packing off intervals. If we encounter a hot zone, we stop drilling and switch to a contingency plan.

Panel Question 2: Do you prefer using multi-level monitoring systems in single boreholes? If so, which systems do you prefer? In your experience, what are the benefits and liabilities to using them?

Johnson: There are many multi-level monitoring systems available, and they each have their advantages

[1] The following writeup is a summary, not a transcript, of the panel session discussions.

and disadvantages. The selection of the appropriate system is site dependent with some of the important issues being the type and degree of contamination, risk of cross-contamination or packer failure, available funding, ability to check and maintain packers, and permanence of the multi-level system. Multi-level monitoring systems are not necessarily "permanent" solutions. Some systems are better described as "semi-permanent", because you may choose to sample and monitor discrete zones over an extended period of investigation, remove the packers for additional geophysical or hydraulic work, and (or) remove and grout the well for a permanent completion. My preference for a type of system depends on the nature of the site and the availability of funds. At "hot" locations, I prefer nested wells with short intervals. There are also conventional-type packers (such as the RockTest packers that have been used for over a decade at the USGS Fractured-Rock Research site at Mirror Lake). These were, however, positioned in the borehole on steel rods, and steel is not allowed at some sites. The Westbay's MP System® also works in these situations, but is more expensive – kind of the Cadillac. The cost of using multi-level systems can be an issue, but the risk of cross-contamination might outweigh the cost of a discrete-zone system.

Davies: Region 3 has not used continuous multi-channel tubing (CMT), but has used nested wells, the Westbay MP System®, Solinst multi-level sampling ports, and clusters of small-diameter wells. My preference for a particular use is site-specific, depending on the nature of the site, budget, fracture spacing, the number of intervals to monitor, the location of the hot zone, etc. When drilling in or near a suspected high concentration area, I prefer single wells completed at specific fractures/fracture zones.

Ballestero: There has been a dramatic paradigm shift with regards to well sampling systems. In the monitoring of overburden wells, the paradigm is typically to employ sampling and monitoring equipment that is easily installed and removed from wells. The paradigm shift for bedrock wells is dedicated devices in the well, yet we seem to want the flexibility of easy removal. The ensuing data is but a small piece to a complex jigsaw puzzle (unknown flow field, unknown gradient field). Installing dedicated vertical isolation equipment in bedrock wells requires a tremendous amount of equipment reliability within a highly complex system. One must consider the consequences of a partial or complete equipment failure, because spare replacement equipment is not typically available. This decision to use certain systems requires a value judgment that includes: site security reliability of the power source, presence of rodents, longevity of fixtures above and below ground, access (and maintenance of access), ease of installation, costs ($$$ and personnel time), and operator training. When drilling in a hot spot, I also prefer using a single well with a targeted interval. Away from a hot spot, multi-level devices are acceptable. For your objective, ask yourself the question, "What is the consequence of a partial or complete failure of the in-well equipment?"

Panel Question 3: Is there an open interval length for finished monitoring wells that should not be exceeded?

Davies: It depends on where the geophysical testing indicates the fractures are. You don't want an open interval that extends across different head or concentration values. In Region 3, we typically have a lot of competent rock between fracture zones.

Johnson: The appropriate length of the screened interval depends on the borehole data, but first I consider state regulations when determining a maximum completion interval. For example, in New Jersey, the maximum length for a monitoring well screen is 20 feet. After meeting all regulatory criteria, the borehole geophysical and hydraulic data should guide the completion design. Specifically, you would want to place packers so as to prevent vertical flow within the borehole. Another important consideration is how you are going to sample the isolated zone. If the completed zone needs to be purged, you will want to have a short isolation zone with a minimal purge volume.

Ballestero: Although the final decision is site-specific, I think that 5 to 15 meters is the maximum length for an open interval. First, consider the well hydraulics. If two or three fractures are 40-feet apart, but hydraulically connected, I would consider leaving an open interval. However, hydraulic testing should be done. As with overburden wells, it is possible that distinct chemistry zones exist requiring a multi-level completion.

Panel Question 4: What methods of water sample collection in bedrock wells do you prefer? Do you sample bedrock wells differently than overburden wells?

Ballestero: This is also a site/well specific question. Dedicated systems are very convenient. The care, maintenance, and transport of bedrock samples is typically the same as overburden wells; however, there are some differences in collection. For example in my work, microbiologists drive scheduling, drilling methods, and how samples are collected, including anaerobic methods.

Johnson: I don't have a preference in sampling methods. I think it is important to understand how the sample was collected and what the advantages and limitations are of each sampling method.

Moderator: Have you used the FLUTe socks with ports?

Johnson: I haven't used FLUTe socks with ports.

Ballestero: The FLUTe system is equipped with a U-tube column and Y-fitting (with check valve) at the bottom. One arm of the Y goes through the wall of the sock and into the formation to collect the water. Nitrogen gas is forced through the other arm to force the water sample out. The movement of water through the system is discontinuous. The system is sampled with a gas purge method—forcing gas down one side of the U-tube and pushing well water up and out the other side.

Davies: How does FLUTe monitor head?

Ballestero: A pressure transducer is connected to the fitting of a port that goes through the wall of the sock. The transducer cable then runs inside of the FLUTe and up out of the top of the well head.

Davies: It is important to use the same sampling technique for each sampling event. In my experience, water sampled with a pump in fractured bedrock can draw the sample from an area distant from the borehole, due to the nature of the fracture network. Sampling the same well with a low-flow system will draw the sample from a much closer area. As a result, there can be a dramatic difference in the observed chemistry of the well samples.

Johnson: I have sampled CMT systems using a peristaltic pump. The results were comparable to the samples collected with a submersible pumps and packers. It has been questioned whether good samples can be collected in fractured rock when a dedicated pump is not installed. At a site with a fracture at 80 feet bgs and a head that rose to 20 feet bgs, we collected samples with a peristaltic pump. Where the head could not be maintained within the reach of a peristaltic pump, we sampled the zones with a Waterra pump. Regulators at that site were satisfied that the results were comparable. However, a word of caution, the head should not be dropped below the level of the packer, or it can cause the packer to fail.

Panel Question 5: What frequency/timing of water sampling events should be used for bedrock wells? Are they similar to overburden wells?

Johnson: The frequency and timing of water sampling bedrock wells should be similar to overburden wells. However, for monitoring head in bedrock wells, I would recommend some continuous monitoring to identify daily, weekly, and seasonal fluctuations to determine natural and (or) anthropogenic stresses.

Davies: For the most part, the frequency and timing are similar for bedrock and overburden wells. I can think of an exception at a site with springs which were not karst related. The water quality of these springs can vary as much as an order of magnitude when sampled during different seasons. For trend analysis, it is important to sample them during the same season.

Ballestero: If you know that seasonality exists at a site *a priori*, then you can collect a sample each season. If you are not sure if seasonality exists, then you need to sample more frequently (e.g., monthly) to see if it does. So a basic guideline is 2 to 6 events for each suspected time step (if seasonal is expected but unknown, the sampling monthly would help to establish that there is seasonality, if recharging river water is suspected during high flow periods that last for a few days, then daily sampling is warranted)). With regards to direct precipitation recharge effects, the frequency of sampling will depend on the frequency of rainfall events. For example, if a region experiences 100 rainfall events per year, then wells should be sampled once or twice per day during the recharge period in order to identify the nature of the time series. With regard to anthropogenic stresses, the frequency of sampling will depend on the nature and frequency of the stressors. For example, the frequency of sampling may depend on whether a pump and treat system runs all day or just part of the day.

Johnson: Other concerns to consider include freezing, flowing wells, the inertness of the sampling system (you might do a laboratory analysis of any materials that go into the borehole), failure of packers, hooking up electronics—to ensure the transducers do not act as sacrificial anodes and minimizing lightning-strike potential.

Panel Question 6: If you drill a deep well through numerous sets of fractures, and it takes a day or two to install the packers to isolate intervals, at what point do you trust the samples from the intervals? Do you conduct time series sampling, do you purge a certain amount first?

Johnson: We have used some CMTs for three years, and we have encountered some maintenance issues, including freezing problems that caused inflation-line blockage, and packer failure when pressure drops below 6 psi. We monitored the packer pressure every time we checked the water levels to ensure the packers exceeded 10 psi, and we re-inflated the packers to 20 psi. Typically the pressures held pretty well, but typically needed adjustment after sampling.

Davies: Once the packers are set, the interval is purged, monitored for stabilization criteria and sampled. Typically the sampling results indicate a vertical distribution of contamination, which would lend credence to the interpretation that the intervals were isolated. It is important to carefully evaluate the geophysical and hydraulic information previously collected from the borehole for the potential for water moving within the borehole.

Kent Novakowski (Queen's University): Regardless of the device used and the concentration measured, it won't be representative of the concentration in the fracture. There will be at least some small amount of dilution that will alter the results. Cross contamination is another issue. Cross-circulation patterns depend on the hydraulic relationship of the contributing and accepting fractures. It is important to collect as much data as possible, before making decisions. For example, complete the geophysics and hydraulic testing before choosing positions to set the packers. It will take 20 times longer to clear up a packered interval than it did to contaminate it. We need not be overly concerned about the length of time that a well is left.

Ballestero: While the water chemistry of a sample may not be exactly representative, we still must rely on it to assist with decision making.

Panel Question 7: Do any of you have long-term experience using CMTs?

Johnson: We have used some CMTs for three years, and we have encountered some maintenance issues, including freezing problems that cause line breaks, and packer failure when pressure drops below 6 psi. We monitor the packer pressure every time we check the water level to make sure it exceeds 10 psi.

Bill Brandon (Region 1): To illustrate the potential impact of the long-term use of a dedicated sampling system, in the 1990s, we installed a large number of Westbay MP System® wells at Loring AFB. Ten years later, we detected vinyl chloride in an unexpected location. After testing, we concluded that the PVC used at that time for the manufacture of the sampling system was the source of the contamination. We had to replace all the wells at significant cost.

Johnson: At Mirror Lake, we used steel and RockTest packers, which have remained in the ground for 10 years without failure. This may be an acceptable alternative for sampling and monitoring head, if metals aren't an issue at a site.

Panel Question 8: Have you successfully used small diameter wells completed at various depths within the well bore (using a sand pack at each screen interval, separated by grout)?

Davies: Yes, we have used them successfully.

Ballestero: We've used 2-inch diameter wells with success.